BUILDING TYPOLOGY FOR RISK ASSESSMENT: CASE STUDY ANTAKYA (HATAY)

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1 INTRODUCTION

1.1 The SERAMAR-Project

In close collaboration with local partners, Earthquake Damage Analysis Center (EDAC) at Bauhaus-Universität Weimar initiated a Turkish-German joint research project on Seismic Risk Assessment and Mitigation in the Antakya-Maras-Region (SERAMAR) [EDAC, 2004]. The ancient city of Antakya lies in the southernmost tip of Turkey, and is currently built on an alluvial plain through which the river Asi flows (see Figure 1). The city, founded in 300 BC, has been an important confluence of states, faiths and peoples from its earliest times. As with many other urban settlements in Turkey Antakya has experienced a rapid expansion during the last several decades, with many vulnerable buildings added to its stock.

1.2 Seismicity

The Antakya Maras Region is affected by the South Anatolian Fault and is therefore classified into the highest seismic zone of the current Turkish code [TMPS, 1998]. Figure 2(a) indicates the seismicity in and around Antakya over the last 18 years. Although major events are missing during that time, an earthquake of magnitude M_w 5.8 occurred in Antakya on January 22, 1997 resulting in moderate structural damages. So it can be expected that in the near future stronger events could be happened.

Since October 2006, three buildings are instrumented by strong-motion recorders [Schwarz et al., 2007]. Until now, 17 recordings could be assigned/ identified as earthquake recordings with a Magnitude $M_L > 3$ according to [KOERI, 2008], however around 230 earthquakes occurred within a 200 km radius around Antakya. Most of them couldn't be measured because of the settings of the trigger-level. Nevertheless, around 80 further recordings were stored, which cannot be clearly identified. It can be records from earthquakes with a magnitude smaller than M_L=3.0 or other types of excitation. Figure 2(b) illustrates all occurred and measured events since October, 2006. The strongest (M_L=4.3) one occurred on October 9th, 2006. (The main parameters of the measured/ assigned earthquakes, i.e. date, time, epicentral coordinates, local magnitude M_L, focal depth h etc., are given by Abrahamczyk et al., 2008.)

Antakya has suffered by many major earthquakes in the past, notably in the years 110, 115, 527/28, 1822 and 1872. Judging by historical precedence, major earthquakes on this branch of the Dead Sea-East Anatolian fault system have a real potential of occurrence in the city. The project is concerned with the damage and loss prognosis under scenario earthquakes similar to size of historic events. Therefore, comparable events can be taken as deterministic scenarios to quantify the damage potential and to identify the most critical areas and the probable damage extent.

(a) Panoramic view over the city Antakya

(b) Impression from the building stock in the City area, the panorama photo is indicating the predominance of RC frame type structures

Figure 1. Study Area for the SERAMAR-Project

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2 SURVEY AND EVALUATION OF THE BUILDING STOCK

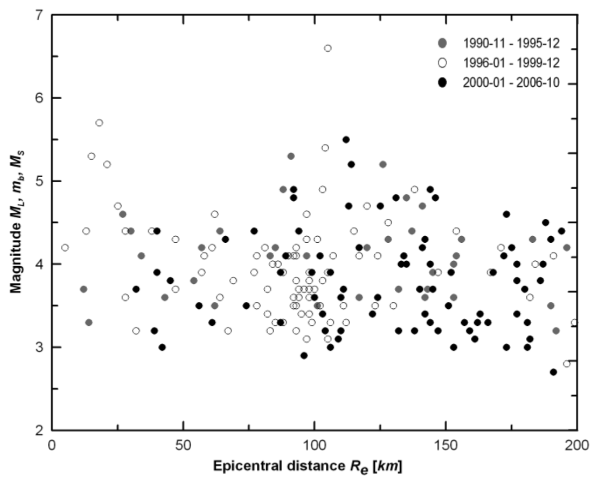
Any systematic elaboration of a building typology for risk assessment starts and fails with the level and quality of the building survey. In general, statistical data being relevant for an engineering evaluation of the buildings' vulnerability are not available. In some cases, information about the age (construction period), the number of stories or - if the archives offer such documentation – undertaken rehabilitation measures can be derived and transformed into GIS-layers (GIS-Graphical Information System).

The experience from different risk studies in Central and Southern Europe performed within the frame of the elaboration and testing of the EDAC damage and loss prediction tools and from the reinterpretation of recent damaging earthquakes (see Langhammer et al., 2006, Schwarz et al., 2008) clearly indicate, that the building stock has to be surveyed. If large-scale earthquake models have to be developed, the investigation of test and model sites may contribute to a reduction of the enormous efforts and capacity requests. In cases where detailed risk scenarios should support socioeconomic and decisions and mitigation strategies the whole building stock has to be considered. Therefore, from the beginning of the project it was decided and agreed among the involved research groups that an engineering evaluation and analysis of the whole building inventory has to be undertaken (Figure 3).

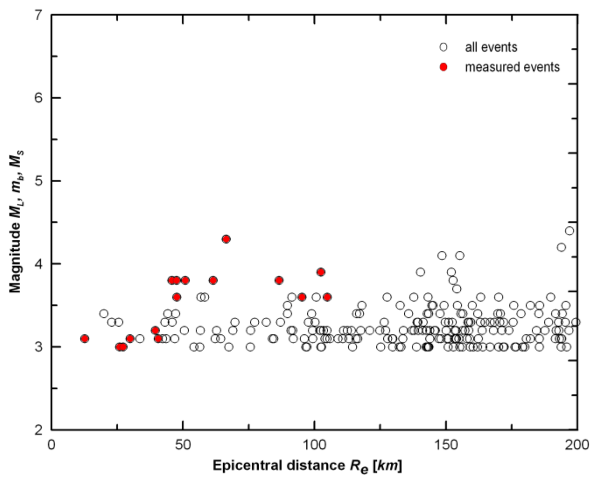
The buildings are classified on the basis of different parameters being relevant for their seismic performance within a multi-step procedure. [Note: The rectangle in Figure 3 indicates the area, for which the results will be further shown.]

Step 1: Identification of structural systems and construction types
In preparation for the building survey the cadastral map of Antakya was processed. After a first rapid screening of the urban areas and a photo documentation of representative buildings, a preliminary classification of the construction types was assembled. On this basis and according to the European Macroseismic Scale EMS-98 [Grünthal et al., 1998] data entry forms were prepared for the dominant building types as well as rules and a guide to recognize and incorporate design defects [Abrahamczyk et al., 2008].

Step 2: Assignment of most probable vulnerability classes according to the EMS-98
Criteria for the allocation of the offered vulnerability classes are given (see section 3). In addition to the common census of the building types further criteria are investigated in order to conduct a more detailed vulnerability assessment with regard to the post-processing. This concerns e.g. criteria of layout irregularity as well as structural peculiarities which could yield to special damage pattern. Starting from the historical city center the whole town was investigated. Figure 4 illustrates the distribution of the construction types as an outcome of the building stock survey, which was also used to assign the vulnerability classes acc. to EMS-98 as it is shown in Figure 6.



(a) 11.1990 – 10.2006



(b) 10.2006 (start of the BMS) –

Figure 2. Recent earthquakes within 200 km radius around Antakya; data from [KOERI, 2008]

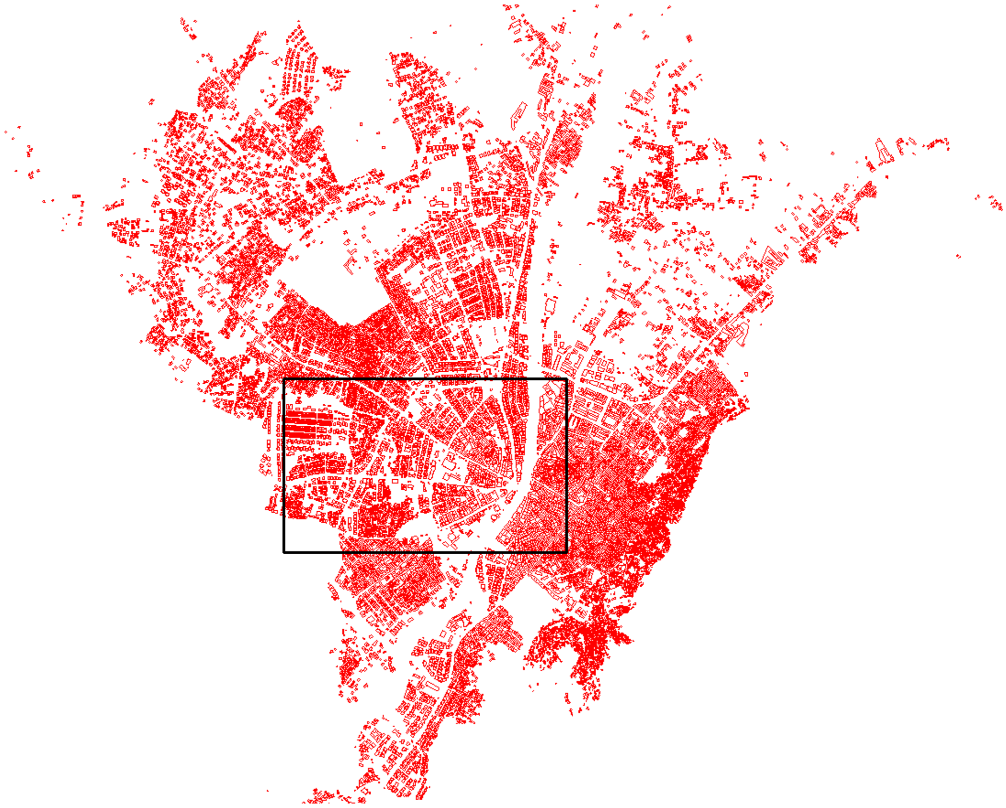


Figure 3. Cadastral map of Antakya; Note: the black rectangle indicates the area for the subsequent presentation of the results of the building survey

Step 3: Sub-classification of the predominant RC buildings (65% of the whole building stock) with respect to their use (commercial, private etc.), the number of stories and particular design aspects (soft stories, cantilevering floor slabs etc.); see section 4.

Step 4: Selection of representative buildings for analytical and instrumental investigation, see section 5.

3 BUILDING TYPOLOGY FOR EMPIRICAL (INTENSITY-BASED) RISK ASSESSMENT

3.1 Assignment of Vulnerability Classes (VC)

It is one of the inherent advantages of the European Macroseismic Scale EMS-98 that for the diversity of building types and structural realizations very stringent rules for their substitution in terms of vulnerability classes are given. The elaborated data entry forms distinguish between the main building types and include practical guidance to select the most probable vulnerability class (see Figure 5).

Derived from a number of field surveys, and subsuming in a condensed manner the collected damage statistics from Task Force (reconnaissance team) missions by engineering experience and judgment, ranges of vulnerability classes could be assigned by using particular different symbols for the most likely vulnerability classes, the probable range and the range of less probable, exceptional cases. The user has to decide the appropriate class by considering and evaluating the vulnerability affecting factors (building structure and material, regularity, particularities in the ground and elevation plan, quality of workmanship and maintenance) and in case of engineered structures upon the level of Earthquake Resistant Design (ERD). Therefore, the building typology for empirical (intensity-based) risk assessment is limited in a robust way to the assigned Vulnerability Classes (VC), ranging from A to F. Transition classes (e.g. BC) are explicitly allowed.

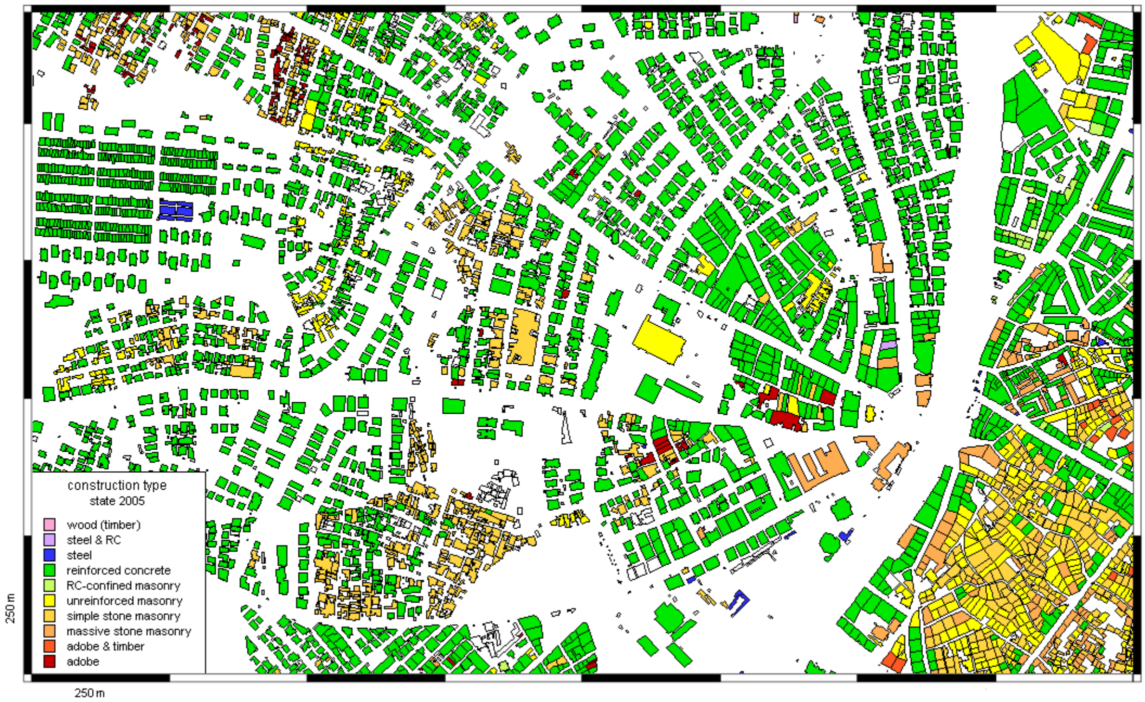


Figure 4. Distribution of the construction types as a outcome of the building survey

3.2 Results for the study area of Antakya

For each vulnerability class, the EMS-98 provides a description of the probable quality (damage grades) and extent (quantity of their occurrence) in dependence on the level of shaking. As an important outcome of the building survey the “present state” of the existing building stock can be classified. After having surveyed the whole building stock of Antakya the following information enable the refinement of the intensity-based scenarios:

- Composition of vulnerability classes for each building type, i.e. MM-massive stone, MS-simple stone, RC – RC frames etc.
- Average vulnerability class for each buildings type (as well as optimistic and pessimistic exceptional cases)

Simplifications of the intensity-based scenarios are possible if average vulnerability classes are determined for buildings in certain administrative units, districts or raster elements. In each case and as the major outcome of the engineering risk assessment damage grades have to be given for different scenarios. The Vulnerability Class is a direct indicator for the damage; e.g. in area with low average vulnerability class higher damage will occur.

Examples		Ranges of vulnerability classes (A, B, C, D, E, F)	Assign-ment
		very seriously pre-damaged (before-collapse state)	A
		pre-damaged/weathered state **and** irregular plan or elevation shape (e.g. soft story)	B
		pre-damaged/weathered state **or** irregular plan or elevation shape (e.g. soft story)	B-C
		without earthquake-resistant design (ERD)	C
		with moderate level of ERD	C-D
		with high level of ERD	D

.... probable range; ——— less probable, exceptional cases; ○ most likely

Figure 5. Part of the cheat sheet for RC frame buildings

It is often recommended to avoid any presentation of too sharp address-oriented vulnerability assignments, for practical application, i.e. it might be sufficient to indicate the scenario damage after a "smoothing procedure" in micro-scale area elements.

4 BUILDING TYPOLOGY FOR ANALYTICAL (GROUND MOTION BASED) RISK ASSESSMENT

4.1 Search for a new approach

While the steps 1 and 2 are related to the empirical, intensity-based approach of seismic risk assessment, any reliable analytical (ground motion based) approach requires a further sub-classification of the predominant building types and the identification of their representatives. They should be suited for structural modelling and should enable the determination of displacement-based vulnerability functions. It has to be emphasized that these vulnerability or fragility functions have to be derived from the existing building stock. In this context, the building typology will not follow classification schemes of common risk software packages which also offer a set of more or less refined standardized functions. As it becomes more and more evident too, these functions are quite uncertain with respect to their evaluation and their applicability to the regional particularities of buildings and construction techniques in other countries.

For this purpose, a new approach of seismic building instrumentation and monitoring will be applied; it implies the calibration of the analytical models on the basis the real building behavior, instrumentally detected and/or recorded response parameters [EDAC, 2006]. The allocation of reliable database is regarded as the basic requirement in order to establish ascertained measures and to generalize them on the basis of sociological acceptance analyses [Lang et al, 2006].

4.2 Definition of representative building types

4.2.1 Story Classes (SCi)

The characterization of building types for analytical investigations requires that single objects preferably represent a large number of buildings of the same group/category. The advantage of the investigation area Antakya consists in the fact that a major portion of the building stock can be traced back to Reinforced Concrete (RC) frame type structures which can be analytically investigated to predict reliable building damage. Around 65 % of Antakya's building stock consists of Reinforced Concrete structures, which led to the decision to sub-classify these structures into different Story Classes (SCi). Three different Story Classes are defined as follows: SC1 ($n \leq 3$), SC2 ($3 < n \leq 6$) and SC3 ($n > 6$); n number of stories.

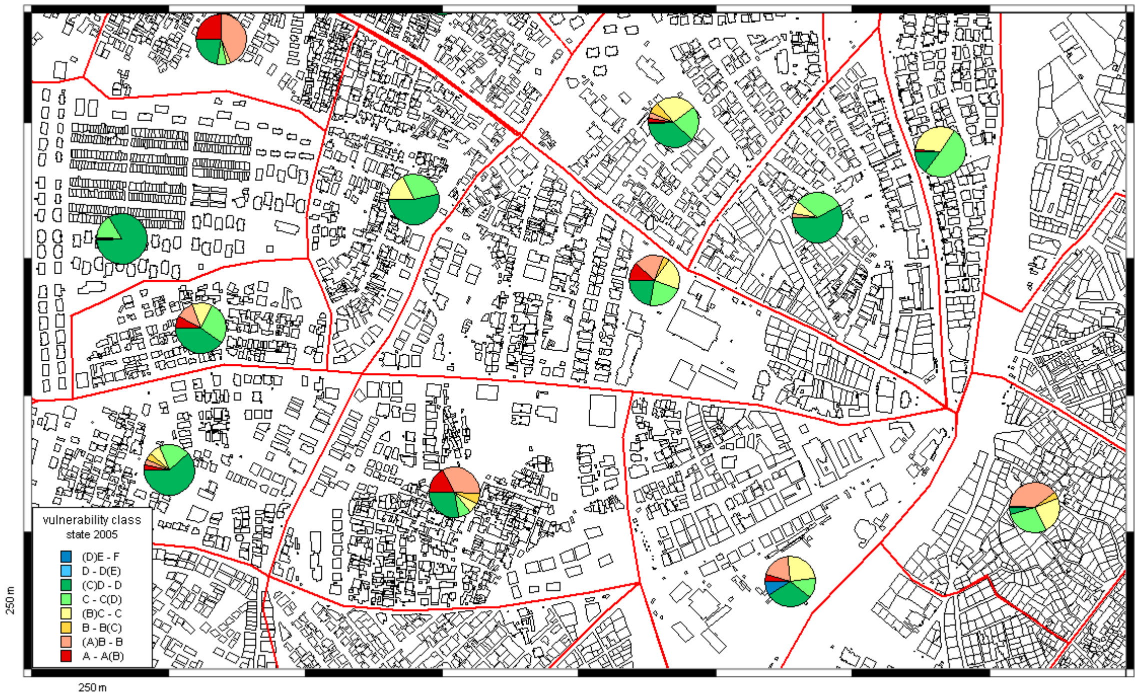


Figure 6. Distribution of the assigned vulnerability classes acc. to EMS

Figure 7 provides an impression of the distribution of RC frame structures classified into Story Classes (SCi) in the City Center of Antakya (cf. Figure 2). From the GIS-mapping it becomes quite evident that other building typologies than RC structures are prevalent in Antakya especially in the historical inner parts of the city (the 'Old Town' and adjacent areas along the eastern hill side, see Figure 1). They will be processed in later phase of the project and have to concentrate on the traditional masonry type structures.

4.2.2 Proposal for a more refined "Codification"

The definition of building types requires the abstraction and reduction of the building characteristics (which is often hidden by the externally appearance) to the failure and damage-determining criteria of the structural system under seismic impact. This means, the defined building types have to preliminary differentiate the different vulnerability classes of the existing buildings and to anticipate comparable damage pattern under comparable seismic impact. Therefore, the RC frame structures are further classified according to the following encoding-like order: RC-Use-VCP-VCS-SCi(n)

RC=Reinforced Concrete; Use = PB/CB (Private/Commercial Buildings). Within the recently drafted typology, a more refined description of building types with respect to the primary and secondary vulnerability affecting characteristics (VCP, VCS) has been applied. VCP stands for the ground or primary type (BT) without major damage-enforcing particularities. Secondary aspects (VCS) are related to design or construction defects (and their combined occurrence) like soft story (SS), cantilevering beams/floor slabs combined with soft story (CUS), wildly rampant building (WRB) etc. Special attention is paid to the 'pseudo-regularity (PSR)' as a synonym for the quite irregular arrangement of structural elements leading to relative uncertain transmission and flow of the seismically induced forces. Examples from this (still preliminary) attempt of codification are given by Figure 10.

4.3 Results for the Study area

The composition of RC structures in Antakya as percentage of the defined Story Classes (SCi) and of the defined sub classes within each Story Class can be taken from Figure 8. For the predominant types RC-PB-BT-SC1(2) and RC-PB-BT-SC1(3) about 2000 and 900 buildings, respectively, could be documented as an outcome of comprehensive field surveys. About 25 sub-groups could be distinguished including in each case more than 50 individual objects.

On the basis of the introduced building typology GIS-maps for different subgroups can be prepared. Figure 9 is exemplary illustrating the distribution of RC frame type structures of Story Class SC2 (representing about 25 % of all RC frame structures, see Figure 8a).

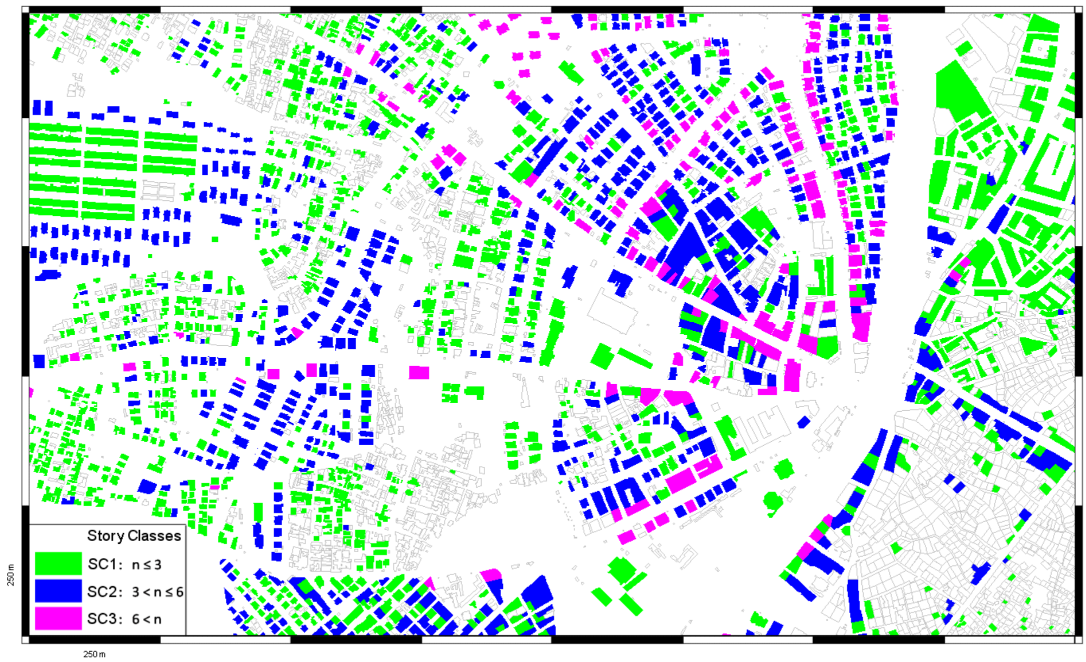


Figure 7. Classification of RC frame Structures into Story Classes (SCi) and their distribution in the central area of Antakya (cf. Figure 2)

5 HYBRID APPROACH COMBINING INSTRUMENTAL AND NUMERICAL DATA

5.1 Elements of the approach

Within a recently started project (Damage and seismic response prognosis for RC frame structures on the basis of hybrid approach combining instrumental and numerical data), it is foreseen to conduct instrumental investigation on several representative RC buildings using the developed building typology.

For each data group, instrumental testing and investigation of selected buildings being representative for the study area becomes an essential part of the project to calibrate the numerical models. On the basis of 3D (three-dimensional) building analysis reliable capacity curves as well as scenario-dependent damage pattern or failure modes have to be determined.

The instrumental investigation will be carried out by dynamic sinusoidal excitation of the building and measuring the building response on different stories and positions at the same time. This will have the advantage of being able to identify not only the periods but also the corresponding type of mode shape. The outcome of the study should be suited to link engineering damage prognosis with highly acceptable mitigation strategies.

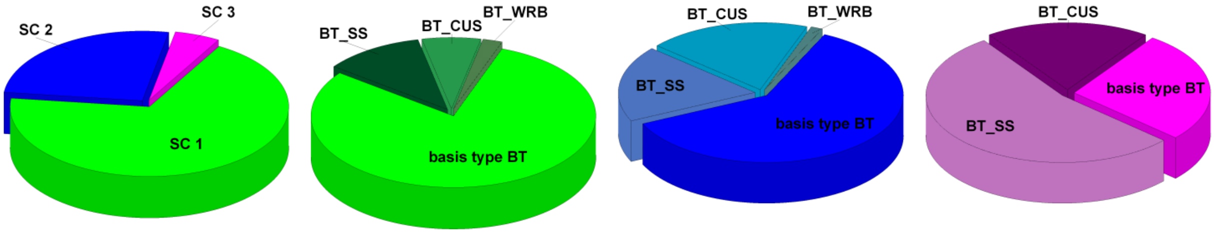
The comparison between the analytical and instrumental investigation of representative buildings of these types will be realized during the next steps of the project.

5.2 Instrumental testing of representative buildings

In the first working phase of this project, eight residential buildings with different number of stories were tested (see examples in Figure 9). Each building was equipped with five or six triaxial velocity sensors Type MS2004+ and the corresponding recorder Type MR2002 (Syscom Inc.). All sensors are connected by a Network Controlling Center (NCC), enabling a simultaneous start of the measurements and synchronous data supply from each sensor. The sensors are oriented at the main axis of each building. In general, two sensors were installed in two opposite corners on the roof and two sensors in the same corners on a mid floor story.

The fifth sensor was installed in the middle of the ground floor or basement if available (see scheme in Figure 10. If six sensors were available, some specialties could be investigated, e.g. the difference between the response of basement and ground floor when the ground floor is connected to the street by some staircases or ramps. Figure 10 shows the instrumentation scheme of the 5 story residential building of Figure 9(b) encoded as RC-PB-BT-SC2(5). Because of the fact, that the corners in the mid floors could not be instrumented, the sensors No. 3 and 4 are installed at the balconies in the middle of two building front sides.
In former studies, external excitation in form of rope relaxation was applied, i.e. structure was pulled by a rope fixed at primary structural elements [Lang et al., 2004]. Also a few numbers of buildings could be excited by an early model of vibration generators (Model VG-1, product of Kinemetrics Inc.) [Genes et al., 2008/2009].

In the ongoing project, a “lightweight” exciter (transportable by two men; developed in cooperation between EDAC and seismotec GmbH; covering a frequency range between 1 and 15 Hz) could be successfully applied. To study also the influence of the excitation point, the exciter was installed at different positions (E1 & E2) at the roof. The normalized FFT response values from the sensor No. 1 is exemplarily shown by Figure 11 (left); the normalization accounts for different amounts of weights which were used during the measurements to cover the whole frequency band. Figure 11 (right) illustrates the related response (deflections of the structure at the sensor point) by an excitation frequency of 3.8 Hz (period T = 0.26 s).



(a) Story Classes *(b) Story Class SC1* *(c) Story Class SC2* *(d) Story Class SC3*

Figure 8. Composition of RC Frame building types in Antakya

(a) RC-PB-BT-SS-SC1(2)

*(b) RC-PB-BT-SC2(5)**

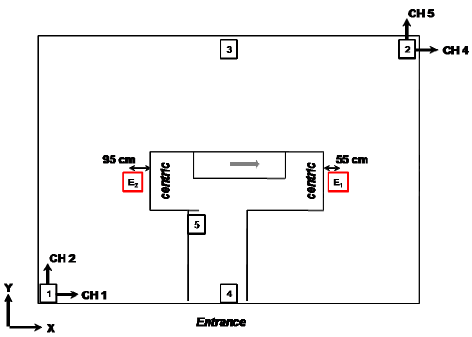
(c) RC-PB-BT-WRB-SC2(5)

(d) RC-PB-BT-CUS-SC2(5)

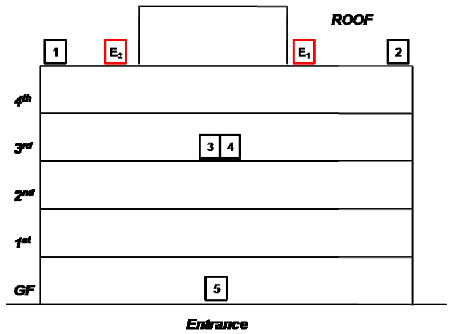
(e) RC-PB-BT-SS-S2(6)

(f) RC-PB-BT-SS-SC3(10)

Figure 9. Examples of instrumentally tested RC frame structures; application of the codification scheme (see also scheme of instrumentaion in Figure 11)*

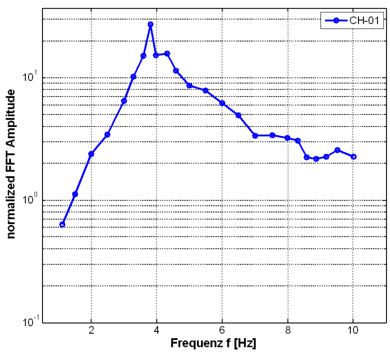


(a) Ground plan



(b) Elevation

Figure 10. Scheme of instrumentation and testing for a building of type RC-PB-BT-SC2(5)



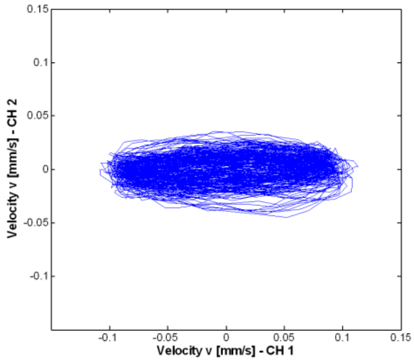


Figure 11. Recorded building response at Sensor No. 1 (left: normalized FFT Amplitude; right: deflections of the structure) by an excitation frequency of 3.8 Hz in x-direction

6 OUTLOOK

Despite the fact that the lower level ground motion could not cause severe shaking or building damage, it is stressed that the interaction between measurement (instrumental data) and analytical investigations provides the entry to obtain essential input parameters to scale and calibrate the models, which at the end, could be used for a realistic damage prognosis. Therefore, the instrumental testing (section 5.2) and the systematic analysis of recorded building response quantities by the Building Monitoring Systems contribute to essential information about the effectiveness of seismic action compared to the induced reaction in case of moderate earthquake, the reliability and limits of model and applied software tools, or the degradation of buildings' stiffness and the change of internal properties in dependence on a time-variable sequence of seismic events.
Finally, the different lines or elements of the hybrid approach have to be brought together to derive ground-motion-based as well as building response-based vulnerability (fragility) functions. The results should contribute to a refinement of the building typology and a further reduction of the derived sub-groups on the basis of their capacity curves, i.e. also for analytical (ground motion based) risk assessment (see section 4) the building typology serves as a more or less indirect entry to differentiate the level/extent of damage in dependence on the elaborated site-dependent ground motion. Therefore, the appropriate, for the prediction of damage best suited building typology will be the result of an interactive hybrid procedure combining the relevant instrumental and analytical data which engineer can deliver from the recent and advanced level of the state-of-the art.

At the end of the project, the remaining question has to be answered to which extent damage scenarios from the empirical and analytical procedure will coincide or indicate the need of further research to explain the divergences. From a series of successful reinterpretations of recent earthquakes using the intensity-based approach support it might be concluded and support the authors' opinion that these results are required to evaluate the results of any other analytical approach if risk has to be assessed for larger city areas.

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Maps are created with the program Mapinfo© Professional 9.0.

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